NUCLEAR REACTIONS IN SHOCK WAVE FRONT DURING SUPERNOVA EVENTS.

A.K.Lavrukhina

V.I.Vernadsky Institute of Geochemistry and Analytical Chemistry, USSR Academy of Sciences, Moscow, USSR

The new unique isotopic anomalous component of Xe(XeX) was found in the carbonaceous chondrites. It is enriched in light shielded isotopes (^{124}Xe and ^{126}Xe) and in heavy nonshielded isotopes (^{134}Xe and ^{136}Xe). We suppose that all characteristics of Xe-X can be explained by a model of nucleosynthesis of the Xe isotopes in shock wave front passed through the He envelope during supernova events. The light isotopes are created by p-process and the heavy isotopes are created by n-procese ("slow" r-process). They were captured with high-temperature carbon grains condensing by supernova shock waves.

1. Introduction

The shock waves from supermassive object explosions pass through an environment of low density (outer envelopes of supernovae) and form a compressed nonequilibrium phase where the high-energy (~10 MeV/nucleon) ion reactions take place. In according to this theoretical model the interactions of protons with the helium nuclei with formation of D and free nucleons, the nuclear reactions with the CNO nuclei and the $\alpha+\alpha$ interactions with the formation of the Li, Be and B isotopes were examined /1,2/. The main difficulty of this model is conditioned by temperature limitation because all these isotopes are destroyed at $T \sim 10^7$K. In region of heavy elements this limitation is not essential and the high-energy ion reactions can lead to nucleosynthesis of some rare isotopes, for example, of the bypassed isotopes by p-process /3/. The (n,γ)-reactions can simultaneously take place because the neutron flux is increased in shock wave front both in fragmentation reactions and in the ^{13}C $(p,n)^{13}$N reaction.

Detailed investigations of isotopic composition of some elements (C,N,O,Ne,Mg,Si,Ar,Ca,Ti,Kr,Ag,Te,Xe,Ba, Nd,Sm,U) in mineral phases of carbonaceous chondrites led to the conclusion about presence the relicts of nucleogenetic origin /4,5/. We believe that one of them is a relict of nuclear reactions in shock wave front during supernova events. It is unique isotopic anomalous component of Xe (XeX). It is present in the carbonaceous chondrites which are nonchanged substance of protoplanetic nebula and contain some relicts of interstellar grains.

2. Results.

The totality of the experimental data /6/ allows to make the following conclusion about the characteristics of XeX. (1)The isotopic composition of Xe-X is characterised by the excesses of light shielded isotopes ^{124}Xe and ^{126}Xe ($^{124}Xe \gg ^{126}Xe$) and heavy nonshielded isotopes ^{134}Xe and ^{136}Xe ($^{136}Xe \gg ^{134}Xe$) (Fig.1). (2)This component realizes only after long action of various oxidizing reagents on meteorite matter. These reagents dissolve all phases enriched in another componets of Xe (solar and planetary Xe).

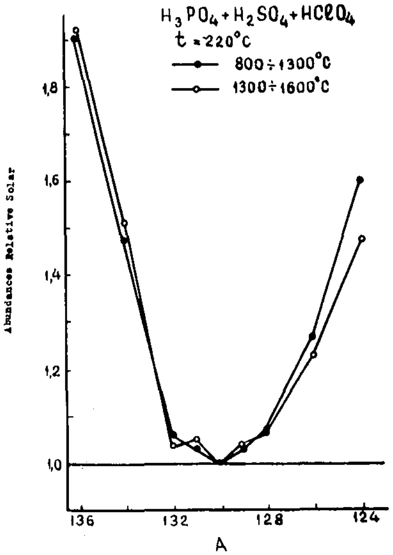

Fig.1.The isotopic composition of XeX (^{130}Xe=1) in acid-insoluble residue of the carbonaceous chondrite Efremovka CV, etched by H_3PO_4,H_2SO_4 and $HClO_4$ at t= 220 °C.

(3)XeX is characterized by the correlations for the isotopic ratios $^{124}Xe/^{130}Xe$-$^{136}Xe/^{130}Xe$ and $^{136}Xe/^{130}Xe$-$^{134}Xe/^{130}Xe$ ($r \geqslant 0.9$). (4)The host phase of XeX is a fine-grained carbon matter of unknown nature. Its content is $\ll 1\%$ of the total carbon content in meteorite. It is very stable to the action of oxidizing reagents. (5)The maximum of the XeX realization as an indivisible component corresponds to 900-1000°C (Fig.2).

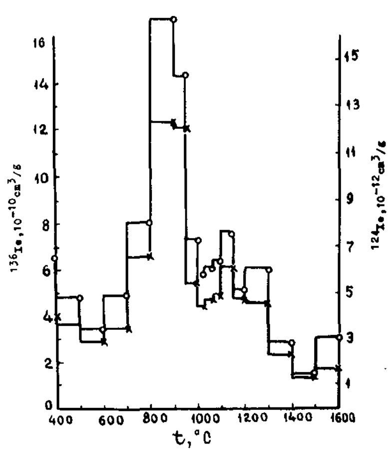

Fig.2. The histograms of realization of ^{124}Xe (1) and ^{136}Xe (2) at temperature annealing of the acid-insoluble residue of the carbonaceous chondrite Kainsaz CO, etched by conc. HNO_3 /7/.

(6)The XeX quantitaty is equal of $\ll 1\%$ of the total Xe in meteorite: it does not correlate with the trapped Xe content. (7)XeX is accompanied by the main quantities of the trapped He and Ne, and by the excesses of heavy nonshilded isotopes ^{84}Kr and ^{86}Kr (not by light isotope ^{78}Kr). (8)XeX is not accompanied by excesses of the heavy isotopes Ba,Nd,Sm and also radiogenic ^{129}Xe and by-passed isotope ^{184}Os.

In this paper it has made an attempt to show that all these reliable observations may be understanded only in the terms of a nucleogenetic origin of XeX. The unique isotopic composition of XeX and its very low abundances withness about exotic process of nucleosynthesis. According to the classical theory of nucleosynthesis /8/ the Xe isotopes can be created in the following nuclear reactions: s-process in the He envelope of massive stars at the stage of red giant (^{128}Xe, ^{129}Xe, ^{130}Xe, ^{131}Xe, ^{132}Xe), r-process at the stage of explosive carbon (oxygen) burning (^{129}I, ^{131}Xe, ^{132}Xe, ^{134}Xe, ^{136}Xe) and in inner envelopes, enriched in ^{56}Fe (the heavy element isotopes), p-process in outer envelopes, enriched in hydrogen, at high parameters ($T \sim 10^9 K$ and $\rho \sim 10^4\ g.cm^{-3}$) ($^{124}Xe$, ^{126}Xe), spallation process with high-energy particles accelerated in front of supernova shock waves /9/ (^{124}Xe, ^{126}Xe), radicactive decay of ^{129}I(^{129}Xe) and spontaneous fission of ^{244}Pu, ^{248}Cm and other (^{131}Xe, ^{132}Xe, ^{134}Xe, ^{136}Xe).

The observed differences of the isotopic ratio values for XeX and solar Xe: ($^{124}Xe/^{126}Xe$) XeX/ ($^{124}Xe/^{126}Xe$) solar = 1.245 and ($^{136}Xe/^{134}Xe$) XeX/ ($^{136}Xe/^{134}Xe$) solar=1.293 (see Fig.1) withness about the XeX nucleosynthesis in the processes which are differ from those for solar Xe. For the understanding of a nature of these processes two facts have a significance. (1)As it was shown by us /9/, the cosmic abundances of ^{124}Xe and ^{126}Xe ($^{124}Xe \cong {}^{126}Xe$) can be explained by their creation in spallation reaction with the high-energy particles accelerated in front of supernova shock waves at $I_p(E_p > 25\ MeV) = 5 \times 10^{21} cm^{-2}$ and $\gamma = 2.5$. (2)The XeX isotopic ratio value $^{124}Xe/^{126}Xe > 1$ (see Fig.1) is typical only for the by-passed isotopes with $A \leq 114$ which by p-process have been created /9/. Hence, ^{124}Xe and ^{126}Xe in that exotic component of Xe have been created also by p-process. One of the real astrophysical objects, in which the condition for p-process can be realized, is the shock wave front (waves of unloading) crossed through the He envelope of supernova. The ^4He fragmentation leads to an increasing of the n_p values and consequently to an increasing of the amounts of the (p,γ)-reaction products on seed nuclei formed in s-process in the He envelope.

The sumultaneous increasing of neutron flux (n_n) leads to fast (n,γ)-reactions. However, the parameters of r-process in shock wave front are essentially different from those of the classical r-process and mainly at the experence of lower n_n value. It leads to a increasing of the τ_n value and to a partial contributions of β^--decay in r-process. This is a slow r-process or n-process /10/. This process is characterized a change of the peak position on the mass curve up to A >130 /11/. The isotopic structure of the heavy isotopes of Xe corresponds to the curve of yields of nuclides in n-process /10/. The maximum yield has ^{136}Xe(N=82) which lies on the decay ladder at N=82 and is the first stable nucleus encountered by the ladder. At high parameters of classical r-process the nuclear structure has not influence on the yields of nuclides. Therefore, just the fact that ^{136}Xe has the maximum yields in XeX withnesses about a presence of n-process simultaneously with p-process in the shock wave front during supernova events. The products of these processes were captured as an indivisible component with high-temperature carbon grains condensing by supernova shock waves.

3. Conclusion

All above-mentioned properties of XeX may be explained by the model of its isotopes formation in the shock wave front during supernova events, the chemical and isotopic compositions of presupernova He envelope, and the property of high-temperature grains "survive" at the conditions which during all stages of supernova remnant evolution have taken place. These grains can be exposed by the action of intensive cosmic ray irradiation, mutual collisions, shock waves, turbulent magnetic fields and other. Thus, isotopic anomalous XeX is a relict of new nonstuded processes of nucleosynthesis, which in the shock wave front during outbursts of supernova or another cosmic objects have taken place.

References

1.Hoyle F. and Fowler, W.A., (1973), Nature,241,p.384.
2.Colgate, S.A., (1974), Astrophys.J., 187, p.321.
3.Audouze, J. and Truran, J.W., (1975), Astrophys.J. 202, p.204.
4.Podosek, F.A., (1978), Annu.Rev.Astron. and Astrophys., 16, p.293.
5.Lavrukhina, A.K., (1980), Nukleonika, 25, p.1495.
6.Lavrukhina, A.K., (1985), Geochimia (in Russian), in press.
7.Shukolyukov, Ju.A. et al., (1985), Meteoritica (in Russian), in press.
8.Trimple, V., (1975). Rev.Mod.Phys., 47, p.877.
9.Lavrukhina, A.K. and Kuznetsova, R.I., (1980), Geochimia (in Russian), p.3.
10.Blake, J.B. and Schramn, D.N., (1976). Astrophys.J., 209, p.846.
11.Black, D.C., (1975), Nature, 253, p.417.